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THE WATER SUPPLY OF THE OLD HICKORY WORKS[1]

By Oscar E. Bulkeley

In the latter part of 1917, the War Department began to realize the need of greater capacity for the production of smokeless powder. Up to that time, the E. I. Du Pont de Nemours Company of Wilmington, Del., had played a most vital part in building plants and furnishing powder to the Allies. Its long years of experience in all kinds of powder manufacture, as well as wide knowledge gained in building and operating plants to supply the Allies, made this company peculiarly qualified to aid the War Department when the need was finally appreciated by that Department. The company drew up plans for a government plant, giving the government all the benefit of its organization and highly specialized knowledge of powder manufacture. The Du Pont Engineering Company, organized within the parent company for handling this large Government work, was given the contract on January 29, 1918. By this agreement, the Du Pont Engineering Company was made the agent of the Government to construct the plant under the supervision of the Government. This contract was superseded on March 23 by another which gave the company greater freedom of action. Under the terms of the latter contract, the company guaranteed completion of the first unit at an earlier date, with consequent earlier production of powder. At the same time the plans were revised to give a daily capacity of 900,000 pounds of powder, an increase of 80 per cent over that contemplated in the first contract.

Old Hickory Works, as the plant was christened, is located at a bend in the Cumberland River about 15 miles east of Nashville, Tenn. It was built for the Government at cost plus the contractor's profit of One Dollar. It is the largest smokeless powder plant in the world, seventy times the size of the largest plant of its kind in existence prior to 1914. Surveys were begun February 6, 1918. Ground was broken March 8. Powder was being produced July 1, two months ahead of contract agreement. As a tribute to this company's organization and ability, let it be said that building of this mammoth plant and placing it in successful operation in so short a time is one of the most marvelous achievements of the war. The entire plant, with the exception of certain special features, was designed by the engineering department of the E. I. Du Pont de Nemours Company.

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The manufacture of smokeless powder requires large quantities of water. When the Old Hickory Works was planned, it was therefore necessary to consider its water supply very carefully, for it must be entirely adequate and reliable. Approximately 100,000,000 gallons of raw water daily would be required, of which 65,000,000 gallons would have to be filtered. The source of water supply, of course, was immediately determined by the location of the industry on the banks of the Cumberland River, or perhaps it would be better to put it the other way and say that accessibility to the Cumberland River, with its abundant water, determined the location of the industry.

The Old Hickory Works water system consists briefly of the following:

1. Two intake pumping stations.
2. Three large parallel wood stave pipe lines about 1½ miles long connecting the intake with the filtration plant.
3. A booster pump house midway between the intake and the filtration plant for furnishing raw water under pressure for cooling purposes.
4. The filtration plant, consisting of alum house, laboratory, five coagulant basins, 96 filter tanks and two reservoirs.
5. Power house flume and 12 service pumps.
6. Distribution systems, which also include the village water works.

The first four items only will be discussed.

Intake pumping stations. In the development of the water supply, there was one condition to be met which was the controlling feature in the design of intake and pumping stations. This was the wide variation in level of the river from the low-water to the high-water stages. Low-water elevation is 401.6, Government datum, while the maximum recorded stage is 456.0, making a total variation of about 54 feet. The pumping station must be waterproof and, to be substantial, must be constructed of massive concrete situated on bed rock, for the water pressure to be resisted would be very heavy.

Furthermore, there must be sufficient weight to prevent floating during maximum flood conditions. To give an added factor of safety, the pumping resources were divided, two stations being built 200 feet apart on centers, the downstream or No. 2 station 600 feet south of Government lock No. 3. At this point the Cumberland River flows due north. The Foundation Company designed the concrete details and also furnished a foreman to supervise the construction work.

Within a cofferdam built of lock steel piling, excavation was carried to bed rock at elevation 383. The foundation consisted of concrete 5 feet in depth, properly keyed into the rock. This brought the floor of the intake chambers to elevation 388, which is the bed of the river. The top of the concrete walls is at elevation 458, or 2 feet above the maximum recorded flood stage and 75 feet above the rock foundation. Above the top of these concrete walls is built a metal-covered frame super-structure. The stations in plan are 69 by 28 feet outside dimension at base, exclusive of the screen chambers.

The walls are reinforced, starting with a thickness at the base of 5 feet and decreasing to 2 feet at the top. The side walls are tied together with reinforced concrete beams in five sets vertically and three in each set horizontally, a total of fifteen beams. Concrete was mixed in the proportions of 1: 2: 4 in the beams and floors and 1: 2½: 5 in the walls. Truscon waterproofing paste was used in the proportion of 5 pounds per cubic yard of concrete. Construction joints were made by an insert 12 inches deep, one-third of the width of wall. On January 8, 1919, when the water stood 40 feet above the pump level, only slight leakage occurred. The screen chamber is divided into halves, so that one-half of the station can be shut down at a time, and is provided with trash rack, stop logs and double sets of screens.

Each station is equipped with five split-suction volute pumps driven by 300 horse power electric motors and designed for a maximum head of 152 feet. The characteristic curve of the pumps is quite flat, so that the capacity ranges from 8500 gallons per minute at 112 feet head to 0 at 160 feet head. The difference in elevation between the pumps and filtration plant gives a static head at the center of the pump shaft of 84 feet. The rated capacity of each station is, therefore, 42,500 gallons per minute or 60,000,000 gallons daily, with space provided and suction pipe installed for two additional pumps.

Each station is equipped with fan and ventilating ducts for supplying fresh air to the pump level, also a sump pump of 400 gallons per minute capacity driven through a vertical shaft by an electric motor located on the main floor above the flood stage. The switchboard is located on a landing two fights of stairs above the pump level. Three 600 kilowatt transformers are supported on the main floor at the top of the concrete walls.

In spite of delay caused by high water flooding over the cofferdam once or twice during construction, a very good record was made. Ground was broken for the first station on April 18, and the first pump was placed in service on June 20, sixty-three days later.

One of the most interesting things in connection with construction and operation of this intake was the condition under which operation was first undertaken. The walls of the pit were approximately a third the way up, at elevation 419. Data from past records showed that this was safe for that season of the year. Means of access to the pump level was by climbing down the form bracing. There was no cover except tar paper protection about 6 feet square over the motors. The switchboard was a temporary one set up a hundred feet outside the station and 2300 volt current was supplied direct from the power house, whereas the permanent installation called for 2300–6600-volt step-up transformers at the power house and a corresponding step down at the intake. By the time the transformers arrived, the line loss had become as high as 20 per cent.

Pipe lines and booster pump house. All the water delivered by these stations was to be conveyed through three 42-inch wood stave pipe lines as far as the booster pump house, a distance of about 3800 feet and from this point on to the filtration plant, a distance of 4000 feet, through three 36 inch wood stave pipe lines. At the so-called booster pump house about one-third of the raw water is diverted and delivered through a separate raw water distribution system to the sulphuric and nitric acid plants, to be used for cooling water.

This booster pump house is equipped with motor-driven, horizontal, centrifugal pumps of the double-suction, horizontally split case type. Two pumps have a capacity of 3750 gallons per minute and four pumps have capacity of 7500 gallons per minute against a head of 120 feet, making a total rated capacity of 37,500 gallons per minute or 54,000,000 gallons daily.

All the wood stave pipe used at the plant is machine-bound and made up in the factory in random lengths. The greater part of it, at least, is manufactured from best white pine. Some troubles were experienced in the operation of these wood stave pipe lines, mostly during the first few weeks of service. Occasional failures developed, some due to defective bands or resulting from injured bands. Warping of the staves and shrinkage caused by exposure to the weather were quite serious in certain cases.

Of course, it is well to bear in mind that this pipe was subjected to an unusually severe test on account of the very magnitude of the work undertaken at Old Hickory. There was the constant stimulus to turn out powder in ever increasing quantities for the support of the American forces. In the eagerness to complete any part of the work when production definitely awaited its completion, the work was literally driven to the limit. Labor was inefficient and railroad deliveries were such that materials must be taken when they could be obtained. Undoubtedly, the wood stave pipe installed in the plant received rough handling and most of it withstood the weather for several months prior to installation. However, there is no question of the appropriateness of its use. The cost was probably one-third of what cast iron or steel would have cost and either of the latter, if obtainable at all in such quantities, would have been so delayed in manufacture that powder production could never have been realized as early as it was. Experience with wood stave pipe proves that it is highly desirable when placing new pipe in service to allow several days for the wood to soak and swell, during which time the pressure should be very gradually increased up to the specified working pressure.

Each one of these pipe lines is provided with air release valves at high points and one 12-inch air vent open to the atmosphere at the booster pump station. There are 24-inch risers from the wood stave pipes extending up to tees, the branch openings of which provide connection to the suction header of pumps. The 12-inch vent pipe is attached to the vertical leg of this 24-inch tee.

These air vent pipes were the means of one peculiar phenomenon which proved very troublesome in operation. The elevation of the booster pump house floor and of the surface of the water in the subsidence basins at the outlet end of the main pipe lines is practically the same, so that the only head on the suction side of the pump at the booster pump house is the friction head existing between there and the subsidence basins. Any sudden variation in the discharge of water at the intake, caused by the interruption of electric current or the starting or stopping of pumps there, produces sufficient surge in the pipe lines to cause an inrush of air at the air vents, uncovering the suction of the pumps at the booster pump house. It is therefore necessary always to be careful in starting or stopping pumps at the intake to avoid interrupting service at the booster pump house.

Alum house. At a distance of about 300 feet before reaching the subsidence basins, water destined for the filtration plant is treated with sulphate of alumina. This is accomplished in the alum house containing the coagulant feeding apparatus. Storage for 700,000 pounds of alum is also provided next to a railroad siding.

The feeding apparatus is arranged in two units of three solution tanks each. These tanks are 10 feet in diameter, constructed of cypress staves 10 feet long and 2 inches thick. Each tank has a dissolving tray, float indicator and graduated scale board for indicating the height of solution, and is also provided with agitators for agitating and maintaining a uniform density of solution. These agitators are driven by a bevel gear and pinion actuated by a friction clutch on each agitator, so that any agitator or any individual tank may be thrown out of use. The main shaft over the tanks is driven by belt from an overhead line shaft.

From the tanks the solution flows into orifice feed boxes about 18 by 24 inches and 18 inches deep, of cast iron, lead-lined, having a float-valve inlet control. The outlet is provided with an acid bronze calibrated orifice feed valve for measuring the flow into another feed box, called the constant-head feed box. This is also cast iron, lead lined, and has a fresh water connection controlled by a ball and float for admitting sufficient fresh water in addition to the solution to maintain a constant head on the pump suction. There is a motor-driven centrifugal pump for each tank, with a capacity of 15 gallons per minute, which pumps the solution into any one of the 36-inch raw water lines as desired.

The principal feature of the feeding apparatus is its exceeding flexibility. A 1½ inch lead feed pipe runs from each unit to each one of the 36-inch raw water lines, thus making two feed pipes supplying each raw water line. Coupled with this duplication, any set of feed boxes and pump may take the solution from any tank in the unit and deliver it into any one of the three pipes.

Subsidence basins. Strangely enough, data on Cumberland river water were not available from which to determine the proper treatment for filtration. However, high turbidities were to be expected, as was later found true in the actual operation of the plant. For the sake of low first cost, a period of only one and one-half hours coagulation was provided. There are five reinforced concrete subsidence basins, 150 by 59 by 13 feet deep, with a capacity of 800,000 gallons each. The three 36-inch wood stave lines discharge into a common cast iron header, which in turn delivers into each basin through a 36-inch pipe controlled by a sluice gate at the basin. The outlet from the basins to distributing or coagulated water flume may be controlled by three 20 by 20-inch sluice gates. Each basin has an overflow and three 12-inch drain valves along the center axis.

Filter plant. The filter plant consists of eight units of twelve filters each, making a total of 96 filters. They are of the gravity, rapid sand type. While reinforced concrete units could have been built for the same cost, wood tanks were favored because they could be erected in less time and would have a much higher salvage value if it were ever desired to move the plant at some future time. The total filter capacity is 65,000,000 gallons daily, exclusive of wash water, which is based upon the customary practice of 2 gallons per square foot of area per minute. The plant is very substantially built but with none of the artistic valve stands, loss of head controllers and other appurtenances found in most municipal plants. It was built to deliver clean, pure water, free from turbidity and harmful bacteria, and it is entirely successful. Six filters in each unit are placed in a row on both sides of a pipe gallery where there is an influent pipe and wash-water pipe line common to the twelve filters. This pipe gallery is immediately under the operating floor and in turn the filtered water gallery is directly under the pipe gallery, the floor of the latter being properly protected to prevent any water which might be discharged upon it from passing through the floor and into the filtered water. The filters themselves are over a wide concrete drain which carries all waste water from washings into the plant drainage system.

The filter tanks are 17 feet in diameter, having staves 7 feet 6 inches long, built of first quality well seasoned redwood lumber, $2\frac{3}{4}$ inches thick. Each tank is bound with seven $\frac{3}{4}$-inch round steel hoops, each hoop having three substantial draw lugs. Each tank has a 3 by 6-inch segmental shelf around the inside, supporting an 18 by $\frac{3}{16}$ inch sheet steel plate and a semi-circular steel trough across the center of the filter, communicating with the trough formed by this segmental shelf and the 18 by $\frac{3}{4}$-inch sheet steel plate, all forming the wash water and distributing trough. The collection system consists of a semi-circular cast iron manifold which rests on the bottom of the filter tank. On each side of this manifold are attached 1½ inch galvanized wrought iron strainer pipes placed on 6-inch centers. The strainer pipes have two rows of orifices approximately $\frac{3}{16}$ inch in diameter spaced 6 inches apart in rows at an angle of 45 degrees off the vertical axis, with the orifices on the lower side of the pipe nearest the filter floor and arranged on 3-inch centers, staggered. The strainer pipes are capped on the outer ends. The connection to the effluent and wash water piping system is made through the bottom of the tank and into the center of the manifold.

Gravel was placed in five layers. The size and depth of each layer are as follows:

LAYER NUMBER	PASSING SCREEN WITH OPENINGS AS BELOW	RETAINED ON SCREEN WITH OPENINGS AS BELOW	DEPTH
	inches	*inches*	*inches*
1	2½	1	9
2	1	⅝	4
3	⅝	⅜	2
4	⅜	$\frac{3}{16}$	2
5	$\frac{3}{16}$	10 meshes per inch No. 20 wire	1

The gravel was graded and placed very carefully. The sand is a selected grade of hard silicate material, free from loam, clay, vegetable matter, etc., having an effective size of not less than 0.35 mm. nor more than 0.55 mm. and a uniformity coefficient of not less than 1.6 nor more than 1.8. The sand is about 30 inches deep, the top of it coming practically even with the bottom of the wash water troughs mentioned above. Both the sand and gravel came from a bank near Montgomery, Ala.

Washing the filter bed is accomplished in the usual manner by a reversal of flow, using filtered water. The specifications called for a minimum wash rate of 15 gallons per square foot of filter area per minute. Since the rate of filtration is 2 gallons per square foot per minute and equivalent to a velocity or drop of 3¼ inches per minute on top of the filter bed, the wash rate recommended is 7½ times the rate of filtration and equivalent to a rise of 24 inches per minute. Practice showed that with this rate the fine sand particles were being lost. A rise of 18 inches per minute is the maximum safe wash rate. The washing process requires five or six minutes for each filter, and under normal conditions of water, washing once every twelve hours has proved satisfactory, although six-hour periods have been necessary at times. The amount of wash water averages about 4 per cent; 2500 gallons per minute are required for washing one filter.

As no loss-of-head controllers were provided, it is necessary to rate each filter from time to time. This is done every hour by closing the influent valve and by means of a hook gauge observing the number of seconds for the water to drop 3¼ inches. From a specially prepared table the daily rate of filtration corresponding to the time may be read. The time at full rated capacity is sixty seconds. The sum of the ratings on all the filters gives the rate of filtration of the entire plant.

According to specifications, the filters were to be operated under a head not to exceed 12 feet. As a matter of fact, it would be impossible to exceed this, as there is only 12 feet difference in level between the water on the filters and that in the filtered water gallery.

A filtered water flume extending along the entire side of the filter house receives water from the filtered water gallery of each unit, delivering it over 12-foot wide weirs into either clear water reservoir as desired.

Reservoirs. The two reservoirs are adjacent to the filter house, the outer wall of the filtered water flume serving as one wall of the reservoirs. They are 200 feet square in plan, 9½ feet deep, built of reinforced concrete, provided with cover, and a central baffle wall insures good circulation. Their total capacity is 5,000,000 gallons or two hours storage.

The floors are 6 inches thick, reinforced with ½-inch square rods placed 2 feet on centers both ways. The walls, 18 inches thick at the bottom and 12 inches at the top, rest upon reinforced footings 18 inches deep, which act as a cantilever beam 2 feet long on the exterior and 4 feet long on the interior.

Water discharges from each reservoir through two 42 by 42-inch sluice gates into a valve chamber, thence by gravity through four 36-inch wood stave pipe lines to the power house flume, where it is taken by the service pumps and delivered throughout the entire works and the village.

Filtered water is sterilized as it enters the reservoirs, four chlorine machines being provided for this purpose in the chlorine house built directly above the weirs. They are of the solution-feed manual-control type. These machines take chlorine gas from steel cylinders, measure it in an indicating float meter and mix it with the proper amount of water, then feed it to a chlorine grid placed on the face of the weir, which gives a thorough distribution of the chlorine solution. A drop of 12 inches from the filtered water flume to the reservoir aids in diffusing the chlorine. The usual treatment is from 2 to 3 pounds of chlorine per million gallons of water filtered.

Ground was broken for the filter plant on March 30. The first unit was placed in service on June 20, eighty-two days later. Construction work was stopped seven months after breaking ground, at which time the entire installation was practically completed.

Probably the most striking feature in the construction of the filtration plant is the method employed for placing concrete. The filter house only is 130 by 402 feet. Together with the reservoirs and subsidence basins the ground covered is approximately 480 by 402 feet, over 4 acres. Pouring the entire quantity of concrete was accomplished in two set-ups of a steel tower. The high-line method of suspension was employed, using steel chutes for conveying the concrete to the desired location. Concrete was mixed with a one-yard batch mixer. The tower stood 180 feet high and distributed concrete through a radius of 300 feet. The maximum pour was 316 cubic yards in twelve hours. A similar tower was used at the intake. Here the concrete was more massive and a better record was made, 396 cubic yards being placed in ten hours.

Laboratory. In one wing of the alum house is a laboratory equipped with apparatus and a complete supply of chemicals for making all the required determinations of the quality of the water. Alkalinity of raw, settled, and filtered water is determined twice daily. Turbidity of raw, settled and filtered water is determined every three hours. Bacterial counts of raw water and of filtered water taken at various points throughout the plant, particularly the village, are made daily. Fermentation tubes are also sown daily and gas formers are followed up with exhaustive tests for determination of the presence or absence of B. coli. Color and residual chlorine are also determined from time to time.

Features of operation. The month of November, 1918, was the month of largest consumption. The average turbidity of raw, settled and filtered water was 677, 120 and 1.41 parts per million respectively. The average alum treatment was 1.5 grains per gallon. The average alkalinity of the raw water was 70 parts per million. Bacteria per cubic centimeter standard agar at 37½°C. of the raw water averaged 864, of the treated water 6. In December the turbidity of raw, settled and filtered water averaged 314, 96 and 0.25 respectively. The alum used was 1.36 grains per gallon. The alkalinity of raw, settled and filtered water averaged 63.5, 57, and 55 respectively. The bacteria per cubic centimeter of raw water averaged 921, of treated water 3.1. B. coli are found present in practically every raw water sample. Even though water for the village must travel 1½ miles, there to be stored in a reservoir and repumped into the village distribution system, analyses of samples taken daily at widely scattered locations in the village show a uniformly high quality, low bacterial count and no indication of B. coli.

The only difficulty experienced in delivering an entirely satisfactory effluent occurred during unusually high water. The Cumberland River reached a maximum stage on January 8, 1919, approximately 32 feet higher than the low-water stage. On January 2 and 3 extremely high turbidities prevailed, 4800 parts per million. On December 31, there was a noticeable drop in the alkalinity of the raw water, which continued to decrease until a minimum of 25 parts per million was reached on January 8. While the filtered water tested all right bacterially, turbidities ranging from 1 to 15 parts per million became common. The alkalinity was not high enough to neutralize sufficient aluminum sulphate to cope with such excessively high turbidities. The result was that too much work devolved upon the filters. A stock of soda ash is now kept on hand which may be used to increase the alkalinity artificially. It is confidently expected that with the aid of this soda ash, any like emergency in the future can be met with satisfactory results.

At full capacity the plant would remove 131 tons of suspended matter daily, on an average. With a turbidity of 4800 parts per million, such as prevailed early in January, the removal would be 1280 tons in one day. The cleaning of the coagulation basins is done as needed, usually about once in thirty days, and is accomplished by opening the center drain valves and washing out the sediment with fire hose. The deposit is very easily washed down into the drainage system in this manner.

The first unit put into operation presented at least a novel appearance. One would doubt that a plant could be operated under such conditions unless one had witnessed it. None of the fittings or pipe for the header in front of the coagulation basins had arrived. One 36-inch wood stave pipe had been completed but it was raised up so that it discharged over the top of the basin. This of course did not aid the process of coagulation. The opening in the concrete for the sluice gate was bulkheaded. The coagulated water flume and filtered water flume were bulkheaded off from the units under construction. A small temporary wash water line only was available. Temporary galvanized iron alum feed lines only had to be relied upon. Neither reservoir was completed, the only storage being that of the power house flume and this could only be filled two-thirds full. There was no roof over the filter house and the filter valves had to be operated without valve stands, and there was no laboratory equipment whatever Conditions gradually improved, but for over two months the plant was operated with a maximum of only six minutes storage capacity, but these will be remembered as days when the saving of time meant the saving of lives. Any practicable means or makeshifts which would make possible earlier production or definitely increased production of powder were highly justified.